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# Friction Performance Analysis of Waste Tire Rubber Powder Reinforced Polypropylene Using Pin-On-Disk Tribometer

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**Abstract**

Waste tire rubber powder reinforced polypropylene composites were established with different set of compositions ranging from 0% to 40%, where coefficient of friction for each of them was analyzed by pin on disk tribometer. The tribological effect between the pin-disk reveals of how the reinforcement plays a vital role in enhancing the coefficient of friction as compared to virgin polypropylene. This paper also elaborates in detail of how the matrix, reinforcement, specimen and test were prepared and conducted via critically designed methodology. A specially designed non-metallic parted line mold was used to ease specimen removal. SEM micrographs provides clearer view of what actually happens between the inter layer bonding of matrix and reinforced materials. The promising findings not only save the environment by utilizing waste tires which are often difficult to be disposed, but it also significantly enhanced the coefficient of friction for pure polypropylene which is highly potential to be used in engineering applications. The correlation between these materials was found towards routing an alternative way of how waste tires could be utilized to engineer new composite materials.


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*Keywords*: Friction performance; pin on disc; wear test, waste tire rubber powder; WTR powder polypropylene composite; coefficient of friction

## 1. Introduction

The waste tires and recycled rubber are known as main adverse effects contributor to the environment which is now addressed as a global issue handled all over the world. There were about 1.5 billion waste tires around the world in May 1997. Thus, about 3.2 million tons of used tires are annually generated in Europe, out of which 2.5 million tons life ended tires are significantly utilized for value recovery. The technologist utilizes devices and machines from the range of simple mechanical devices to sophisticated, complex mechanochemical and thermal set ups to rework or reutilize used tires. Few systems are combined together to operate in tandem to produce desired products [1]. Coefficient of friction and weight losses of epoxy-rubber composites has been investigated by varying

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speeds, loads and time [2-3]. It was observed that all the specimens have exhibited very low coefficient of friction and low wear rates under dry sliding condition. Incorporation of silica in PP-NR-RRP composites gave more processing difficulties than carbon black and calcium carbonate filled PP-NR-RRP composites [4-5]. Wear resistant rubber products are being mainly developed on an empirical basis as the scientific understanding of rubber wear is yet to achieve. Therefore, further investigation of the wear mechanism is necessary in order to be able to design rubber formulations and to specify relevant test methods in a rational way, in order to improve the tribological performance of rubber products [6-7].

Maridass Balasubramaniam et al. [8], predicted and optimized the mechanical properties of polypropylene/waste tire powder blend using a Hybrid Artificial Neural Network-Genetic Algorithm (GA-ANN) incorporating various blends of PP and waste ground rubber tire powder with ethylene-propylene-diene monomer (EPDM), and polypropylene grafted malcic anhydride (PP-g-MA) compatibilizer of various concentrations. Four material factors namely WGRT, H-PP, PP-g-MA and EPDM concentration led to 9 trials for optimized recipe with respect to tensile strength, including elongation break, modulus, and hardness. Zhen Xiang Xin et al. [9], investigated the recycling of waste ground rubber tire (WGRT) foaming method using CO2 as the foaming agent in an extrusion foaming process. Multiple samples were prepared with various weight percentage (wt%), but the 20 wt% blend demonstrated as the best cell morphology possessing smaller cell size, better cell uniformity, and higher cell density. The cell density, void fractions generally increased proportionally as the CO2 amount increases.

Expanded Waste Ground Rubber Tire Powder/ Polypropylene Composites has been investigated by [10] using a single screw foam extrusion setup and chemical blowing agent. The relationship between foam structures of foamed PP/WGRT composites was studied. It was claimed via the statistical analysis that, screw speed is the most important factor in determining the cell size and cell density, the blowing agent is the most important factor determining the void fractions. The mechanical behavior of epoxy matrix composites filled with Nano sized silica particles and styrene-butadiene rubber was performed by [11]. The results of the wear test in pin-on-disc mode and hardness test on Rockwell R scale showed that, Nano sized silica particles is able to improve the wear resistance of the epoxy matrix even though the content of the filler is at a relatively low level (1.0-2.0 wt%). This makes it possible to develop novel type of epoxy-based material with improved wear resistance for various applications. A good correlation between mechanical properties and weight contents of the filler materials, hardness and ultimate strength, hardness and wear rate has been observed.

## 2. Matrix and filler properties

The properties of both, polypropylene (PP) being the matrix, and waste tire rubber (WTR) powder as filler were characterized critically to ensure the reproducibility of the composites. The properties of PP and WTR powder are shown in Table 1 and Table 2 respectively.

Table 1: Properties of waste tyre rubber

| **Properties** | **Value** |
|---|---|
| Density | 0.9 x 103 Kg/m3 |
| Specific Gravity | 0.94 |
| Low Temperature Limit | -18$^{o}$C – 10$^{o}$C |
| High Temperature Limit | 70$^{o}$C – 107$^{o}$C |

Table 2: Properties of Polypropylene

| **Properties** | **Value** |
|---|---|
| Density | 0.51 x 103Kg/m3 |
| Specific gravity | 0.90 |
| Young Modulus | 1.3GPa |
| Form | Pallet |

## 3. Experimental investigation

### 3.1. Specimentation

Waste tire rubber (WTR) powder with the particle size of 500µm was continuously dried in the oven at constant temperature of 60$^{o}$C for 24 hours to remove moisture. A non-metallic split mold was designed and prepared to suit hot press molding process. The mold was specially designed with a semi parting line to ease the specimen removal after the hot pressing by breaking it over the line. Each mold consists of five through holes, sized according to the standard specimen dimensions for pin-on-disc operational test. Each mold was then firmly wrapped with aluminum foil to make sure there will be no damage on the specimen due to irregular or burned surface. The waste tire rubber (WTR) powder – polypropylene composite was prepared by mixing the rubber powder at different weight percentage, quantifying 0%, 10%, 20%, 30% and 40% with polypropylene as the matrix. Haake Polylab OD Rheodrive internal mixer with the mixing speed of 50rpm was used for hot mixing process. The mixed composite with their respective weight percentage ratio were then filled into the mold cavities and staged next for 20 ton hot pressing with the temperature of 190oC for 10 minutes, including 4 minutes for post-processing. Once the mold cools down to room temperature, it was split into pieces over the pre-designed parting line as shown in Fig. 1. The WTR powder reinforced PP composite specimens were then carefully removed from the split mold and labeled according to their respective filler composition as shown in Fig. 2.

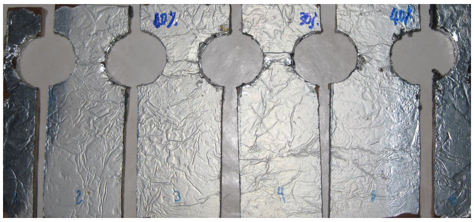

Fig. 1. Aluminum foil wrapped nonmetallic mold.

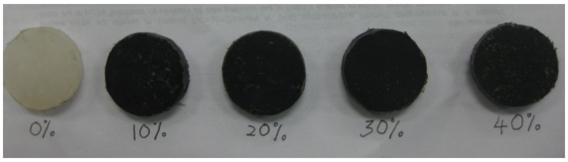


Fig. 2. WTR Powder reinforced PP composite specimens ranging from 0 to 40 weight percentage.

### 3.2. Pin-On-Disc Frictional Test

Friction test for the waste tire rubber (WTR) powder reinforced polypropylene composites have been conducted using CM-9109 pin-on-disc tribometer. The schematic of pin on disc test setup is shown in Fig. 3, where the test was conducted in dry condition using flat surfaced disc. The selected pin diameter was 3.0mm made of copper was held stationary against the counter face of disc with the diameter of 25.0mm. The tribological test was performed at a constant speed of 500 rpm with 20N load for 300 seconds at varying sliding distance. The samples of disc were then removed from the holder after each run and properly cleaned using alcohol.

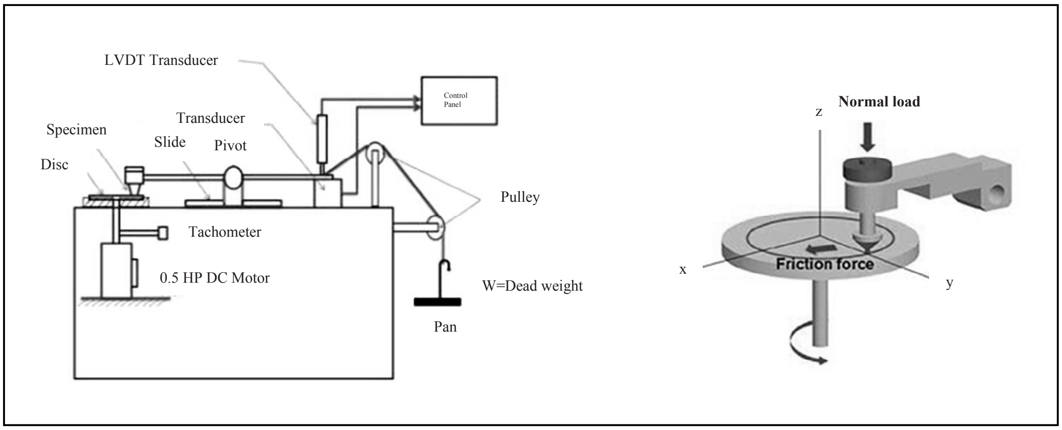


Fig. 3. Schematic of pin-on-disc setup.

## 4. Results and discussion

The results of surface roughness, wear, and coefficient of friction for the engineered composite are elaborated next.

### 4.1. Surface Roughness

Surface roughness of each composition were observed using Mitutoyo SJ-310 profilometer. Three inline observations and their average are presented in Table 3. The surface roughness was observed to be directly proportional to the reinforced percentage of waste tire rubber powder except 20%, where, this could be the optimum level of reinforced %.

Table 3. Observed surface roughness for each composition

| Filler (W%) | Observation 1 (μm) | Observation 2 (μm) | Observation 3 (μm) | Average (μm) |
|---|---|---|---|---|
| 0 | 1.28 | 1.25 | 1.17 | ***1.23*** |
| 10 | 1.49 | 1.32 | 1.29 | ***1.37*** |
| 20 | 1.21 | 1.17 | 1.43 | ***1.27*** |
| 30 | 1.40 | 1.89 | 2.02 | ***1.77*** |
| 40 | 1.93 | 2.34 | 2.18 | ***2.15*** |

### 4.2. Wear Analysis

As for wear test as shown in Fig. 4, the coefficient of friction versus sliding distance was drawn for 10, 20, 30 and 40 weight percentage of WTR powder. Coefficient of friction was observed to be directly proportional with the reinforced percentage, except for 20% it slightly decreased for the same load and speed. This correlates with the result of surface roughness for the same 20%. The plot of coefficient of friction versus sliding distance as shown in Fig. 4 witnesses the proportional increase of coefficient of friction when the % of WTR powder was increased for sliding distance of 78 meters.

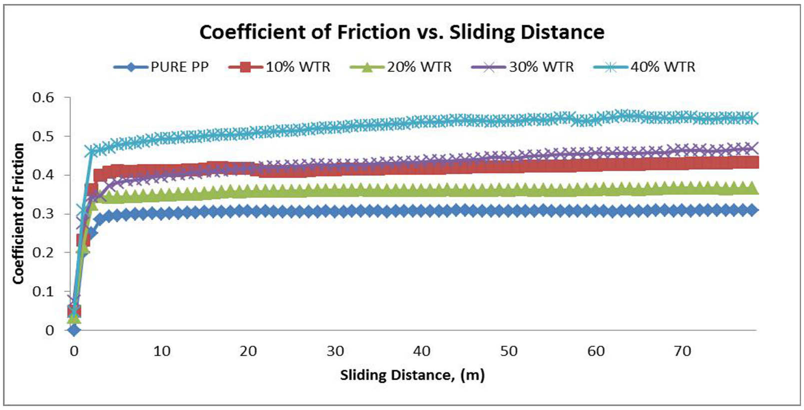


Fig. 4. Wear test results for all compositions.

### 4.3. *Coefficient of Friction*

From the results, coefficient of friction against sliding distance of all the tested samples, the lowest value of coefficient of friction was found on pure polypropylene (PP) as show in Fig. 5. Comparison of coefficient of friction among the composited specimens, the one with 20w% of WTR powder yields the lowest as shown in Fig. 6. From the entire frictional analysis for all composition results of the tested composites, it was found that, the coefficient of friction proportionally increases with the increase of WTR powder weight percentage. Surface roughness has an influence on the friction properties, especially at the beginning of sliding, where, since the pin was in contact just with the peaks of the asperities, the friction properties depend on the distribution of asperities, on their height and their deformation during the sliding process, e.g. on the roughness of the contact surface. Fig. 7 and Fig. 8 witness the increase in their coefficient of friction with the increase of filler reinforcement percentage into the matrix of polypropylene, respectively for 30% and 40% filler.

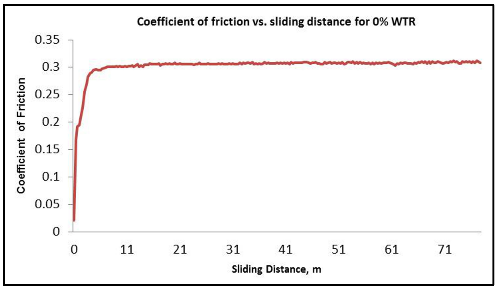


Fig. 5. Coefficient of friction for 0% WTR powder.

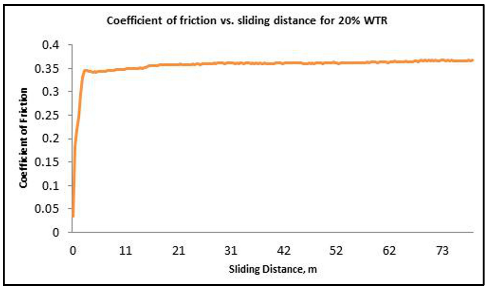


Fig. 6. Coefficient of friction for 20% WTR powder

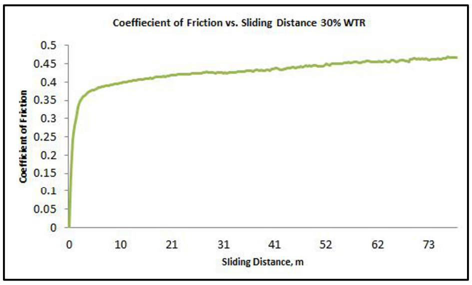


Fig. 7. Coefficient of friction for 30% WTR powder.

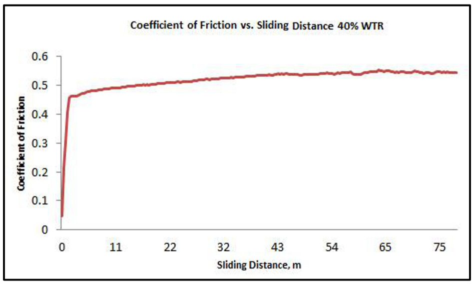


Fig. 8. Coefficient of friction for 40% WTR powder.

In order to investigate the morphologies and microstructures of the inter layer matrix and filler of the prepared composites, Scanning Electron Microscope (SEM) was used for detail observations. Fig. 9 shows the SEM micrograph of the structure for 10% WTR powder reinforced PP with moderately smooth surface structure and exhibits no symptom of plastic deformation or drawing. It was obvious that, the compressive bonding WTR powder and PP exhibits no void, hole or impurities, witnessing sound bonding ability of matrix and filler.

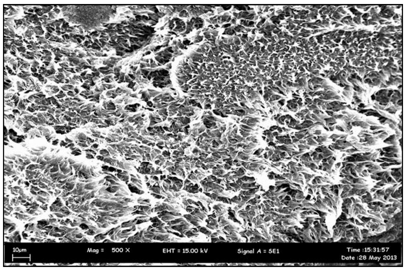

Fig. 9: SEM micrograph of 10% WTR powder

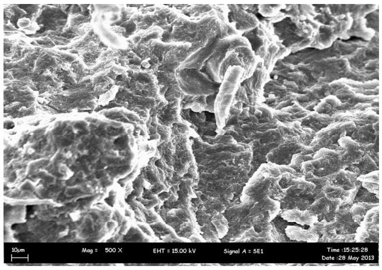

Fig. 10: SEM micrograph of 20% WTR powder

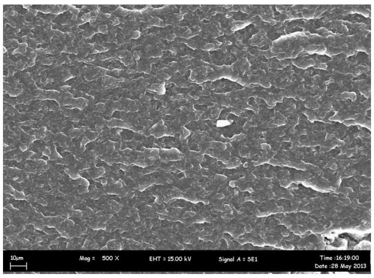

Fig. 11: SEM micrograph of 30% WTR powder

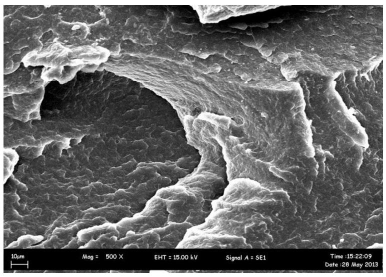

Fig. 12: SEM micrograph of 40% WTR powder

Fig. 10 shows reinforcement of 20% WTR powder provided good wetting behavior between the filler and matrix. Good dispersion and wetting situations may generate desired stress distribution from the matrix to the filler. Thus, the micrograph structure seems to be smoother and the bonding of filler and the matrix are uniform while having a good level of bonding. In general, the micrographic structure of the 10% WTR composite is smoother than 20% WTR. This is probably because the melting of the polypropylene was at the optimum level which leads into better bonding with the WTR powder. An agglomeration of this structure is uniformly balanced between matrix and filler loading.

As compared to Fig. 11 which is reinforced with 10% WTR powder, Fig. 12 shows structured surface of 40% WTR powder which is much rougher than any other w% specimens. This sample would probably experience excessive of WTR powder which led to improper merging of the filler and matrix. Perhaps, this phenomenon would have taken place due to much higher w% of filler composition, where the WTR powder would not have melted fully for uniform flow bonding with matrix. Therefore, voids and holes can be witnessed through the micrographic image, and if this continues, the formed micro holes could propagate into crack to broadcast at quicker rate which will affect the morphological by the rough surface.

## 5. Conclusion

This research work concludes the higher filler loading of reinforcement waste tire rubber (WTR) powder results in proportionally higher coefficient of friction. This is probably due to the nature of tire materials which could not be liquidized even at high temperature, and remain semi solid in the matrix. Thus, the matrix and filler would have bonded properly, but the existence of inter material layer would have caused the disk to rub on the tire material experiencing greater coefficient of friction with the increase of filler percentage. By the way, this reveals how waste tire rubber powder could help in enhancing coefficient of friction of the virgin PP which was originally lower to cater the need for engineering application. Thus, the correlation of the WTR powder and matrix (PP) is well understood in terms of coefficient of friction, where the results can be vastly applied into various related fields.

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